

Review of Potato Research and Development in Ethiopia: Achievements and Future Prospects

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Abstract

Root crops are good sources of food, cash and foreign exchange for the majority of smallholder farmers in Ethiopia. Among root and tuber crops, potato is an important food and cash crop in Eastern and Central Africa, playing a major role in national food and nutrition security, poverty alleviation and income generation, and provides employment in the production, processing and marketing sub-sectors. In Ethiopia, potato production has increased during the “Meher” season as a result of improved varieties, being tolerant to major potato disease, late blight especially in the areas of major potato growing regions of the country. It is a short cycle crop with three to four months cropping cycle, are well suited to double cropping particularly in rain-fed systems and has significant advantage over grain crops which require relatively longer time to mature. Its short growing cycle allows for flexible planting and harvesting times and also permits quick production of foods to augment “hunger months” of August to October before grain harvests when people lack sufficient food to meet their basic caloric and nutritional requirements. The potato crop is cheap but nutritionally rich staple foods that contribute carbohydrates, protein, vitamin C, vitamin A, zinc, iron and minerals which alleviate the problem of malnutrition in subsistence farming areas and towards the dietary demands of the country’s fast-growing towns and cities. Another advantage of this crop is that, it is largely traded locally and nationally, as opposed to internationally. The crop is far less susceptible to large-scale market shocks and price speculations experienced by more widely traded staples, such as grains, during international market crises. As such, it contribute to a more stable food system, maintain nutritional and food security, and are a predictable source of income. To exploit the potential benefit of this valuable crops as food and nutrition security, the Ethiopian Agricultural Research Institute (EIAR) through its implementing federal and regional research centers has been conducting several research and development activities on potato since its establishment in 1966. Since then several technologies have been released, demonstrated and popularized for the larger farming community in the country. The objective of this paper is, therefore, to review potato research and development outputs obtained so far, potentials and opportunities as well as challenges and research gaps for potato production and productivity in the country.

Keywords: Potato; food & nutrition security; achievements; technologies; Ethiopia

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INTRODUCTION

Root and tuber crops are said to be one of the most efficient crops in converting natural resource, labor and capital into a high quality food with wide consumer acceptance (Horton, 1980). The food potential of root and tuber crops has not yet been fully exploited and utilized despite their significant contributions towards food security, income generation, provision of food energy and resource base conservation (Gebremedhin *et al.*, 2008). According to Kolech (2019) potato is considered as a food security crop that helps to meet the rising food demands in the tropical highlands of Sub-Saharan Africa. Due to the potato’s short cropping cycle and higher production per hectare per day when compared to other arable crops (FAO, 2009); potato provides hope for improving the lives of millions of poor farmers in the risk-prone highlands. Root crops are good sources of food, cash and foreign exchange for the majority of smallholder farmers in Ethiopia. The economic and nutritional importance of root crops has been a factor for producing them both under rain-fed and irrigated conditions in all root and tuber producing regions and growing the crops more than one time in a year (Mesfin, 2009). In Africa the area under potato production is about 1.5 million ha with an average yield of 10.8 t ha⁻¹ (FAO, 2008).

In Ethiopia, potato ranks first in the category of root and tuber crops (RTCs) in terms of area coverage and total production. Crop production survey results of private peasant holding of the year 2015/16 indicated that of the total land areas of about 496, 148.99 hectares covered by RTCs, 296, 578 hectare (~60%) and of over 7.21 million tons of RTCs produced over 3.67 million tons (~51%) was potato (CSA, 2016) with an average national yield of 13.9 t ha⁻¹ (CSA, 2017/18). Potato holds a huge (largely ignored) promise for improving the livelihoods of hundreds-of-thousands of smallholder farmers in Ethiopia’s risk-prone highlands. Potato is a very important food and cash crops, especially in the high and mid altitude areas of Ethiopia. It has a promising prospect in improving the quality of the basic diet in both rural and urban areas of the country. Potato has high potential for improving food security, increasing household income and poverty reduction as well as provides important nutrients. It has a high content of carbohydrates, significant amounts of quality protein, and substantial amounts

of vitamins, especially vitamin C (FAO, 2008).

In Ethiopia, potato is grown in a wide range of agro-ecological zones, throughout the year using different growing practices and is considered a “hunger breaking crop” because it can be grown and harvested when cereals don’t mature for consumption other crops fail. Indeed, potato is the only food crop grown to any large extent in the dry season where rain-fall is erratic and unpredictable in the months of March through May (Kolech *et al.*, 2015). Potato tubers are an excellent food source for providing energy from carbohydrates, but are also rich in minerals and vitamins and present high quality protein (Pereira *et al.*, 2005). Egata (2019) described that among African countries, Ethiopia has the most potential of potato production because of the highlands comprises 70% of the country and home to higher percent of the population. Exploiting these production potentials will make the potato crop to play a key role in ensuring national food security (FAO, 2008). It is an important food crop after cereals, in human diet in developed as well as in developing countries (Wheeler, 2009; Kushwaha *et al.*, 2014). Among root and tuber crops in Ethiopia, potato ranks first in volume production and consumption followed by cassava, sweet potato and yam (CSA, 2016). Similarly, it also goes beyond wheat, rice and maize in terms of dry matter and protein production of per unit of area (Romero-Lima *et al.*, 2000).

The major limiting factors to potato productivity in Ethiopia include lack of high yielding varieties, diseases, post-harvest losses due to poor handling and storage facilities, insufficient clean potato seed tubers, poor seed distribution system, and inadequate production technologies (Hirpa *et al.*, 2010). Amongst these factors, post-harvest losses due to poor handling, poor storage facilities and lack of value addition activities are the main potato production constraint in Ethiopia. Ethiopia is among the top potato producers in Africa, with 70% of its arable land in the high altitude areas above 1500m being suitable for potato production (FAOSTAT, 2008). Currently, potato is produced mainly in the North western, Central and Eastern highlands of Ethiopia (Berhanu *et al.*, 2011). Its production is constrained by a wide range of factors that resulting in low yields. These factors include lack of high yielding varieties tolerant to late blight, poor soil fertility, climatic limitation, inadequate seeds, lack of appropriate cultural practices, poor post-harvest management & storage problems, high cost of farm inputs, diseases and insect pests (Gebremedhin, 2013).

Achievements

Research has been conducted over years and a number of technologies have been selected, developed, released, adopted, and popularized since the establishment of research system in the country. Among which variety development for different agro ecologies, crop pest management technologies, crop husbandry, post harvest management and food quality appraisals are the major ones.

Availability of Research Technologies: Potato germplasm of wider genetic base have been introduced annually mainly from CIP and other sources since the inception of potato improvement program in Ethiopia since 1975. And considerable achievements have been recorded improved varieties, agronomic and seed production techniques, IDM, IPM to major diseases and insect pests in the different agro-ecological zones of the country from researches carried in various disciplines. Numerous awareness creating and knowledge and skill upgrading trainings have also been given to farmers and extension workers on the various techniques of potato productions. Over 32 improved varieties were released and/or recommended for wider and specific production areas in different parts of the country. The released varieties give as high as 25 to 40 tons ha⁻¹ fresh potato yield (5.5-8.8 tons of dry matter) under improved management practices. Results of on-farm studies have also revealed that under the farmers condition the yield range vary between 15 and 35 tons (3.3 to 7.7 tons dry matter basis/ha) (Gebremedhin *et al.*, 2001). This has been a big improvement compared to the national average tuber yield of only 13.9 tons per hectare (CSA, 2017).

1. Available Germplasm

Germplasm enhancement: the germplasms source for potato is International Potato Centre and Hybrdiztion of farmers’ varieties with improved one to exploit the potential of the crop. Currently a total of more than 2500 germplasm of potato available at Holetta and Adet research centers. As can be seen the available germplasms are very narrow and this needs strong collaboration among international institutions for germplasm introduction/exchange and strengthen the crossing activities to increase the germplasm pool of the country.

2. Varieties developed

A number of potato varieties have been developed and released in the country. The first improved variety was released in 1987 (AL-624), since then more than 32 potato varieties were developed and released where as eight potato varieties developed in Europe were also evaluated for their adaptation and yield and registered for production in the country by agricultural research centers and Haramaya University (Gebremedhin, 2013).

The local varieties introduced earlier may be the same parentage (Haile-michael, 1979). This intensely shows that the genetic base of the local varieties is narrow; making any progress in improving the productivity of

the crop is unsatisfactory. To make such a progress possible by widening the genetic base of potato, a selection program with a large number of seedling populations was started in 1973 at the College of Agriculture in Alemaya in cooperation with the Institute of Agricultural Research (IAR) and International Potato Center (CIP). A more coordinated improvement work on potato was started in 1975. National potato research programs in sub-Saharan Africa have continuously focused on selection of high-yielding varieties with resistance to late blight (LB) disease (El-Bedewy *et al.*, 2005).

Introduction and evaluation of commercial varieties, introduction and evaluation of germplasm, generation of local population and recently introduction of advance materials are some of the strategies what we have followed to develop varieties widely adaptable, resistant/tolerant to different pests and stresses (Berga *et al.*, 1994). Accordingly a number of variety trials were conducted in different corners of the country to catch different agro-ecologies of the potato growing areas. From these experiments widely adaptable, late blight resistant and high yielder (25-40 tons/ha) potato varieties were released and under production. So far, about 32 improved potato varieties were released and recommended by the National Potato Improvement Program (MoA, variety registry, 2018). Moreover, most of the potato genotypes that have been developed and released in Eastern Africa before 2008 either have genes for vertical resistance to LB or have been developed for horizontal resistance to LB in the presence of unknown resistance (major R) genes, thus named population “A” clones (Landeo *et al.*, 1997). A particular feature of this breeding population is that horizontal resistance was improved in the presence of undesired, unknown major (R) genes for vertical resistance (population A). Their presence, rather than contributing to the overall resistance, made the recognition of true horizontal resistance and effective gene frequency upgrading more difficult (Landeo *et al.*, 1997). Although the Ethiopian Potato Improvement Program (EPIP) has shown progress over the years, further improvement is still needed, particularly in accelerating varietal selection and release schemes and increasing adoption and diffusion rates (Gebremedhin, 2013). Diffusion of new varieties has been lengthy and limited; thus old potato varieties are still present in farmer’s fields covering significant areas. One of the major factors attributed to the low productivity of potato is access to improved varieties. The main constraints to accessing improved varieties are lack of availability of healthy seed tubers and poor seed tuber quality (Hirpa *et al.*, 2010; Gebremedhin *et al.*, 2008; Berga and Gebremedhin, 1994). Adoption of improved varieties is hindered by awareness of the availability and use of improved technologies (Hirpa *et al.*, 2010). In other words, new varieties are struggling to reach larger areas or replace the old ones. Farmers would like to replace their old varieties with new ones because of diminishing productivity, but they usually have not heard of the release of new ones. Even if they are aware, there is no seed supply priced affordably. Therefore, the majority of potatoes growers in the country use local cultivars and poor quality seed tubers which is the major limiting factor for varietal diffusion.

3. Agronomy

3.1. Agronomic Management

The production of potato seed crop can be equally affected by the various agronomic management issues and practices of potato ware crop production. However, the effects of some of the agronomic practices may be more important in the production of potato seed crop. Some agronomic practices in particular can have significant influence on the quality, and yield of seed. Therefore, multiplication of seed crops should involve manipulation of some important agronomic practices towards quality and high seed yield results.

In potato seed production, seed health and size are important seed qualities. Adjustment of plant density in the fields is a good practice to produce a high proportion of medium size tubers. The cost of seed potato is estimated to constitute up to 50% of the total cost of production. It may therefore not be economical to use large size tubers as seed. Rouging and dehauling are also important agronomic practices that can be used mainly to minimize virus infection and bacterial wilt infestation in the field and obtain healthier seed tubers. Rotation, use and application of fertilizers and pest management are conventional potato agronomic practices. However, they can be more critical particularly in potato seed production and need to be properly administered to get high quality potato seed tubers.

Seed tuber size, storage and yield

Any potato seed tuber may be free from biotic factors, but this cannot be realized if it has poor physiological qualities like old exhausted or dried tuber, etiolated, long and thin sprout growth, and old and loose sprout that shades-off from the tuber. The piece-meal harvest, discussed in Chapter 2, is commonly encountered in the highland areas. It allows lately formed small tubers to bulk and attain seed size. Farmers usually save these as seed for sale later as seed or for their own planting in the next season. However, this practice also imposes a considerable challenge to the potato production because it allows accumulation of considerably more tuber-borne diseases. The inoculum’s load can be higher in these tubers than early harvested ones during harvesting all at once and sorting the seed for size and quality. Moreover, the physiological condition of such seed is poor that the final yield is considerably affected. Such traditional and sub optimal husbandry practices perpetuate the use of

seed tuber qualities that fall far below the standard.

In relation to this problem, a study was conducted to evaluate the seed tuber size farmers could use for planting at different altitudes and the subsequent effects on yields. Three released varieties (Menagesha, Tolcha and Genet), and three tuber sizes (25-25, 36-50 and >50mm) were used for the study. The seed tubers were stored in DLS at two locations, Holetta (2400 m) and Galessa (2900 ml). The results showed that seed tubers from the two locations significantly affected yield performance in the following year. The yield of tubers from the higher altitude area, Galessa, was higher. Tuber size also affected total yields, and bigger size tuber (50–60mm) gave the highest yield (34.8 and 21.4 t/ha) in both years.

The yield responses indicated that the seeds from the two locations had different physiological conditions such as fresh weight, dry matter and sprout number attributable to environmental differences in storage. Location differences for time of sprout initiation and growth were similar but variation in sprouts growth was found more associated with the difference in tuber sizes.

Except in few cases, in both years and for all varieties and locations, yield increased with increasing tuber size. Mean sprout height varied between varieties and was higher at Holetta (5.98mm) than at Galessa (4.14mm), but without much difference in tuber weight loss.

The suboptimal agronomic techniques practiced by potato growers in Ethiopia are undoubtedly one of the contributing factors to the existing low average national yield. Agronomic studies have been undertaken by different research centers to develop a package of optimum management practices, together with improved cultivars.

Therefore, research on planting dates, planting depth and method of planting, fertilizer rate and time of applications, and number of hilling during the growing period for seed and ware potatoes, plant population density for seed and ware potato productions comprise the major component of the agronomic/physiology research. Some of these technologies are;

Time of planting: planting time varies from place to place and from variety to variety and also based on growing season. It influences tuber yield incidence of late blight and has significant impact of tuber yield and quality. To secure maximum yield potato should be planted during the time in which favorable conditions prevail for better growth and development of the crop. Planting from, Early June was recommended as optimum planting time for Emdiber (Gurage zone), Holetta (central Ethiopia) and other similar agro-ecological areas (Berga *et al.*, 1994). Similarly, May first to mid May and from May first to June first are recommended as optimum planting dates for late blight susceptible and moderately tolerant/resistant potato cultivars around Adet and similar agro-ecologies. Abdulwahab and Semagn (2008) recommended that last week of May to mid June as an appropriate planting time for optimum potato production in the high lands of Ankober (North Shewa) and other similar agro-ecologies.

Depth of planting: even though optimum planting depth varies with the areas of soil moisture content, soil temperature etc, under Holetta condition planting at 15cms depth followed by 10 and 20cm performs best for high yield and protect from insect pest attack.

Seed tuber size and plant population

Seed tuber size and population density are among the most determining factors of the production and productivity of potato. A potato tuber may at the end of dormancy grow one or more sprouts, and after planting variable proportion of these sprouts develop into main stem. A plant may contain a variable number of this stem as this again is dependant up on the tuber size and treatment of the parent tuber. This in turn affects the number of tubers set, the growth and longevity of the haulm and therefore the performance of the plant and yield (Gebremedhin *et al.*, 2008). Closer intra-row spacing of 10 or 20cm in rows of 75cm apart would be beneficial for seed and larger seed tubers (45-55mm) do better than the smaller ones. Wider intra-row spacing of 30 or 40 cm are better, again on rows 75cm apart, for ware. Similarly, considering the amount of seed tuber required type of output and synergism with other cultural practices, seed tuber size of 35-45mm diameter, 60cm inter-row spacing and ridging once at 3-4 weeks of crop emergence is recommended for seed potato production. However, 35-45mm diameter seed tuber, 75cm inter-row spacing and ridging once at 3-4 weeks from crop emergence is found optimum and recommended for ware potato production at Adet and its surrounding (Tesfaye *et al.*, 2008). Therefore, use of 75 cm inter-row spacing is found suitable for ware potato production with tuber size of > 50 mm diameter. However, use of 60cm inter-row spacing is found ideal for seed tuber potato production.

Fertilizer rate and its application

Potato, as a high yielding crop, consumes more nutrients from the soil at a given time. Many factors may affect the total nutrient consumption of the potato crop. Reports indicate that the effects of season, variety and rate and time of N, P and K fertilizer applications resulted in the removal of mineral nutrients in fresh tubers in the following ranges: N, 2.28–3.57; P, 0.40–0.62 and, K, 3.70–5.41 kg/t (Gunasena, 1969). However, the diversity of soil types, moisture and nutrient regimes, cropping sequences, fertilizer uses and climatic conditions as well as

biotic factors such as weeds, pests and diseases all many affect the sate of soil nutrient flux and use by the growing crop. The extent of use of fertilizer may also be dictated by economic factors like market prices and the economic status of a farmer (Gebremedhin *et al.*, 2008). Considering this problem area specific and economically feasible fertilizer rates were recommended by different research center for different potato growing areas across the country. According to (Tsfaye *et al.*, 2008) fertilizer rates of 108/69 and 81/69 kg/ha N/P₂O₅ are economically feasible in South Gondar and Gojam areas, respectively. Similarly, 110kg/ha nitrogen and 70.5kg/ha P₂O₅kg/ha are recommended for optimum potato tuber yield in nitosol and light vertisol of the high land of North Shewa (Abdulwahab and Semagn, 2008). Berga *et al.*, (1994) also reported that 165/90 N/P₂O₅ recommended as feasible rate for the central shewa area and this recommendation is still in use in the central and southern part of the country as blanket recommendation. In the same fashion, 146/138 N/P₂O₅ were recommended for the high lands of Hararghe. These recommendations may not work for the current market, soil fertility status and other climatic variables. Therefore, considering the variability of the input-output market and soil fertility status, detail soil test based fertilizer rate studies should be carried out.

Potato Ridging/Cultivation

Ridging, which refers to the practice of hilling or earthing up the soil around the potato plant, is a normal practice in potato production. Riding is practiced to obtain sufficient earth or soil and form a well-shaped ridge that helps to loosen the subsoil for good aeration and/or to cover the tubers with sufficient layer of soil. On lighter soils ridging presents no difficulty, and it is very useful if the soil depth is shallow. However, on heavier soils, ridging may present a problem unless it is done under suitable conditions and good timing in relation to moisture content of the soil. Proper ridging increases tuber yield by creating favorable condition for tuber initiation and development. Poor ridging in potato may expose the tuber to sunlight, high temperature, disease and insect damage. Studies show that a yield loss as high as 8% is sacrificed due to poor ridging. The frequency and optimum of ridging may depend on variety, soil structure and workable soil depth (Gebremedhin, 2013). The highest yield was obtained from plots with the highest frequencies of four and three times ridging. Generally, increasing ridging frequency substantially reduced green tubers from 53.3% in no ridging to 29.5% at four times ridging. In a similar study conducted at Adet, ridging frequency had no significant effects on parameters like tuber size, marketable and total yields. The results under Holetta conditions showed that yield and tuber quality can be affected by ridging and at least twice ridging is very necessary. Light soil and heavy rainfall areas require more frequent ridging. Whereas, in light red soils care has to be taken to reduce insect damage and greening by modifying planting distance and increasing frequency of ridging. In ware potato production, good cover-up of soil does substantially reduce unmarketable tuber yield due to greening (Gebremedhin *et al.*, 2008).

Intercropping of potato

Intercropping of potato with maize is a common practice in northwest Amhara region. Consequently, an experiment was conducted at Adet for two consecutive years (1997-1998) to identify economically feasible intercropping pattern. The result of the experiment was also statistically analyzed using total monetary value (TMV) of the system and economic yield of each component crop. Moreover, the land equivalent ratio (LER) of each intercropping system is calculated. From this work intercropping of potato with maize in 2:1 and 1:1 (potato: maize) row spatial arrangement are found superior in their order and recommended for potato production at Adet and its surrounding (Tsfaye *et al.*, 2008). In addition, intercropping study of potato and maize was mad at Bako for three cropping seasons. Maize and potato were arranged in 1:1 ratio alternating within a row (15 x 75cm) and between rows (37.5 x 30 cm) including sole planting (75 x 30 cm). The yield of potato in an intercropped field was as high as sole potato in one of the three study seasons. Intercropping was found economically advantageous than sole cropping as the maize grower could get potato yield as bonus in addition to maize yield (Gebremedhin *et al.*, 2008).

4. Crop protection

4.1. Potato Disease Management

The potato is prone to many diseases caused either by bacteria, fungi, viruses or mycoplasma. Among major potato disease, Late blight, caused by *Phytophthora infestans*, remains the most devastating disease in potato and worldwide losses each year to late blight are conservatively estimated at more than \$6 billion (Haas *et al.*, 2009). Late blight is generally the most important disease wherever potatoes are grown in the country. Traditionally the crop is grown during the off-season using the short rain that falls during February–April and sometimes with supplementary irrigation when available. The main reason for not growing potato during the long rainy season, despite the high yield potential of the main season crop, is the severe threat posed by late blight. The local varieties do not cope with the disease pressure in the main rainy season and often are wiped out particularly in the highlands. However, the use of resistant varieties is a powerful, viable and environmentally friendly alternative or supplement for the current, commonly deployed chemical control strategies (Haesaert *et al.*, 2015)

to control the diseases. Viruses and bacterial wilt are also very important diseases affecting potato production (Bekele and Eshetu, 2008). Among these, late blight (LB), followed by bacterial wilt (BW), potato leaf roll virus (PLRV), and potato virus Y (PVY) were the most important diseases. LB was widely distributed where the crop is grown under rainfed conditions (Bekele and Yayinu, 1994). In this report, BW was detected and found restricted to the mid-and low altitudes. Currently, however, it has also been recorded in high altitudes (>2400 masl); virus diseases were more prevalent in the mid-altitudes than in higher. Studies on host-plant resistance, loss assessment, cultural control measures, and integrated management have been conducted on many diseases. Promising results have been obtained. The level of economic loss of late blight has been determined for some varieties. Furthermore, the use of integrated late blight management (ILBM) or integrated disease management (IDM) in reducing blight damage has been emphasized. The result showed that early planting of moderately late blight tolerant variety with one or two fungicide applications significantly reduced the disease, thereby, highly increasing the tuber yield. Attempts have been made to determine the physiological races of *Phytophthora infestans*. Results of chemical control trials indicated that a fungicide (Ridomil MZ 63.5% WP) containing Mancozeb and Metalaxyl was very effective in controlling LB (Bekele and Yayinu, 1994). In a host resistance study, potato varieties that are tolerant to late blight, early blight and bacterial wilt have been identified (Baye and Gebremedhin, 2013).

An integrated bacterial wilt control research was conducted in a farmer participatory approach, where different options were compared. The options were (a) an improved package (IP) that consisted of clean seed, a less susceptible variety, and improved cultural practices, (b) a farmer package (FP), which consisted of a farmer's variety and farmers' seed, planted under the farmers' cultural practices, (3) clean seed of a less susceptible variety planted in farmers' cultural practices (CSFCP), and (4) farmers seed planted under improved cultural practices (FSICP). All the options significantly reduced wilt incidence and increased potato yield as compared to FP; with IP performing best. The options were all economically beneficial and resulted in marginal rates of return of 1034% for IP, 805% for CSFCP and 634% for FSICP (Berga, 2001; Berga *et al.*, 2005).

Potato is naturally infected by over 36 viruses. About 50% of these viruses are dependent on potato for their survival and spread, while others usually have major hosts apart from potato. Viruses and virus diseases constitute a major constraint to potato production in developing countries including those of SSA. The diseases are often overlooked because the symptoms are usually not as striking as those incited by fungi and bacteria. The virus diseases cause reductions in yield quality and quantity (Salazar and Accatino, 1990). Berhanu *et al.*, (2011) described that, evidence of the occurrence of potato viruses in Ethiopia was first reported in studies conducted in central, south and southeast Ethiopia during the 1984 and 1985 crop seasons. The results of these consecutive studies indicated the presence of *Potato virus X* (PVX), *Potato virus S* (PVS), *Potato leaf roll virus* (PLRV), *Potato virus Y* (PVY), *Potato virus A* (PVA) and *Potato virus M* (PVM). Regarding viruses, their effect in potato production is primarily due to their accumulation on seeds and cause degeneration with in short period of production. There is a need to strengthen the tissue culture laboratory in order to supply disease-free seed to seed producers and minimize the effect of viruses on potato yield. In addition, the existing sites for seed production should be strengthened. It is also crucial to forge strong linkages between potato seed producers and the research system. The potato plant can become systematically infected with viruses following transmission either mechanically or through vectors. Whereas, nearly all of these viruses are transmitted vegetatively through seed tubers. PVY and PLRV, the two economically most important potato viruses, are also horizontally transmitted by aphid vectors under natural conditions. Green peach aphid (*Myzus persicae*) is the most important vector of these two viruses worldwide, while other aphids like potato aphid (*Macrosiphum euphorbiae*) can act as less efficient vector.

4.2. Potato Insect Pest Management

Potato is attacked by a number of insect pests. In the last two decades or more, the major insect pests that stay on potato did not shift and include: cutworms (*Agrotis* spp. and *Euxoa* spp.), red ants (*Dorylus* spp.), potato aphid (*Macrosiphum euphorbiae*), green peach aphid (*Myzus persicae*) and the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae) (Bayeh and Tadesse, 1992). Among these insects, potato tuber moth (PTM), cutworms, and aphids were the most important. Research has been made to inform management options against these economically important insect pests. Many survey reports indicated that PTM was known to damage potato only in the warmer areas, though major production areas mainly cover the highlands. Monitoring of PTM was conducted using PTM sex pheromone trap at Holetta. The result showed that the peak months were January, February, and June. Unlike the field situation, monitoring in the store showed no obvious peak record (Bayeh and Tadesse, 1994). Aphids in potato, though, were more important as vectors of virus diseases than as pests. Monitoring work was conducted using yellow water traps at Holetta, and during the monitoring different aphid species were recorded. The peak months were January, April, and November–December. The dominant species were Brassica aphids, green peach aphids, and potato aphids (Bayeh and Tadesse, 1994). In this work an attempt was made to correlate the population fluctuation with some abiotic

factors, temperature, (minimum and maximum temperature in °C), rainfall (mm), and wind speed (km/hr). The result showed that rain fall and minimum temperature had negative effects, whereas the influence of the other two factors was non-significant.

5. Potato Seed tuber/planting material production

The Ethiopian Potato Improvement Program, with almost 35 years of CIP's technological support through its regional office in Kenya and its headquarters in Peru, has been able to release more than 31 varieties; however, the rate of adoption and diffusion has been quite limited. Among the released varieties, Belete, Jalenie, Gudenie, Guassa, Gera, Horo and Dagim are the most widely grown potatoes recently in major potato growing areas of the country. In most cases, the main limiting factor for variety diffusion was insufficient amount of clean seed. It is characterized by the limited formal seed system that was overwhelmingly dominated by the informal system. Current yields in Ethiopia are low which is about 13.9 t ha⁻¹ (CSA, 2017/18) but could easily be doubled or tripled. Moreover, the adoption and coverage of 25.2% of the total potato area in the country with improved varieties have partly contributed for the witnessed productivity gain (Labarta *et al.*, 2012). Potato's production value is estimated at 403 million USD (CSA, 2014). Perhaps the most significant constraint to increasing productivity and overall production is the chronic shortage of good quality seed tubers.

A pre-requisite to a successful and sustainable seed scheme is a continues supply and maintenance of pathogen free pre-basic seed. Provision of disease free planting materials is the responsibility of research institutions in the country. To provide these diseases free planting materials a number of research activities have been conducted. Evaluation of some rapid multiplication techniques (stem cutting and aeroponics) were made under local conditions. Tuber yield increased with increasing number of stem cuttings per hill from 1 to 3 and with closer spacing. Stem cutting results revealed that the rooting abilities of stem cuttings differed with cultivar and media, where as fine sand was found to be the best locally available medium (Berga *et al.*, 1994). Currently, millions of mini-tubers are producing under rapid multiplication for experimental and for pre-basic in our TC labs and aeroponics structures at Bahirdar and Holetta. The conventional multiplication rate of potato (1:3) is promoted to 1:30 by rapid multiplication technique (RMT) especially by using aeroponics system (Abebe *et al.*, 2014).

6. Post harvest Management

In Ethiopia potatoes are basically stored for two reasons: ware and seed. Farmers use different traditional potato storage system depending on the use. However, these storage facilities are not proper to keep the quality of tuber for more than 1–2 months (Endale *et al.*, 2008). Since potato tuber is a living botanical organ, it loses weight and quality during storage. Ethiopia lacks proper storage facilities; farmers keep potatoes in the ground for a long period or forced to sell their potato harvest at low prices during harvesting and buy seed tubers at high prices during planting. This is remarkably reduced tuber yield. A study on extended harvesting period in Alemaya revealed that yield of marketable tubers was reduced by 60% when tubers were harvested at 210 days after planting as compared to a harvest at 120 days (Berga, 1984). Similarly (Gebremedhin, 1987) reported that significant yield reduction (70-100%) was shown as harvesting was delayed from about 125 days to 230 days at Holetta.

Therefore, the low-cost diffused light store (DLS) for seed tubers developed by CIP has been evaluated under the Ethiopian condition. It was found to be very useful and efficient storage technique. Consequently, it has been adopted by many potato farmers' in many parts of the country. Agajie *et al.*, (2008) reported that, 87% of the central part and 25% in the north and west are using DLS to store their improved potato variety seed. Thus, practical training was given to farmers in different part of the country and they are aware of the new seed storage technology that is, diffused light store (DLS). Generally, better quality seed tubers are obtained with storage in DLS than in traditional dark storage, and as a result, productivity of potato in Ethiopia increases.

In DLS tubers can be stored 8-9 months without much loss. They can also produce 3-4 sprouts, which are green, and strong consequently yield will be high. If possible seed store should be covered with aphid proof screen to avoid insect entrance.

7. Scio-economics and research extension

7.1. Demonstration and pre-scaling up

Technology transfer is both a technical and non-technical process, and it should be carried out in collaboration with stakeholders. The main objective of technology transfer is to improve peoples' welfare gradually and continuously. In Ethiopia, there are still some drawbacks of technology transfer such as inappropriate channels, applicability of the technology, and lack of integration. A number of potato technologies were promoted through participatory seed multiplication and scaling-up from production to utilization in different parts of the country. These promotional activities sought to facilitate the diffusion and adoption of potato technologies that will improve potato production. To transfer these new technologies, two phases of activities were facilitated.

In the first phase, participatory seed multiplication was conducted over the last 10 years. At this stage, researchers, Farmers' Research Groups (FRG), development agents, subject matter specialists, development project workers, nongovernmental organizations, and other stakeholders were involved in planning, monitoring, and evaluation. This was to promote awareness on better adoption of new technologies and quality seed for further dissemination. In the second phase, before launching the actual activity, an inception workshop was held with all stakeholders. Researchers played a catalytic role. On the basis of group consensus, the seed, which is maintained during the evaluation and seed multiplication phase, was distributed to all members of the FRG. In this way the potato technologies are diffusing to potato farmers. Currently, potato farmers are using almost all components of the potato production package. Throughout the whole process of evaluation, seed multiplication, and scaling-up of improved technologies, participation of farmers and stakeholders was useful to promote the diffusion and adoption of improved technologies, knowledge, and skill of quality seed production, and postharvest handling. This established the farmer-to-farmer seed exchange and information dissemination system. In the process, a number of field days were organized to demonstrate the production, postharvest handling, and utilization of potato. In general, technical backstopping and creating good public-private partnership and technology transfer system are the most important issues that need more attention.

8. Capacity building (Training)

During potato seed productions using on-farm participatory approaches like farmers field school different trainings were undertaken based on the crop phenology with practical exercise and sessions on farmers' fields. These include;

- Land preparation.
- Importance and use of quality seed tubers.
- Time of planting ridging.
- Application of fertilizers and its time of application.
- Integrated diseases and insect pest managements.
- Type and time of fungicide applications for LB control.
- Dehaulming/removal of the above ground parts and its importance.
- Importance of grading/sorting based on size & quality.
- Post harvest handling techniques (use of diffused light store).

9. Potentials and opportunities for potato seed production

Increasing the production and productivity of potato crop is an important factor in ensuring food and nutrition security, and livelihood and health improvement of the nation. In addition, export potential for potato is enormous, which shows the possible contribution of the sector for the country's aspired economic growth and poverty reduction agenda.

- Availability of improved technologies, eg. Varieties, Management, IDM, etc.
- Growing interests of public and non-governmental organizations in potato seed
- Increased farmer knowledge of potato seed production and management
- High demand for quality seed, and high returns
- Good networking for intra-regional nuclear seed exchange
- Strong support of the International Potato center (CIP) and other stakeholders
- Conducive policy framework
- High irrigation potential and conducive market proximity and niche
- High yield per unit area as compared to other crops
- Suitable agro-processing for (French fryies, Crisps, Glucose, etc)
- High demand of potato and its product in local and export markets
- Availability of improved varieties and technologies

10. Challenges and research gaps

The potential of producing sizable potato products appear to be influenced by several constraints. However, the main challenge is related with the seed system of the country. Potato is produced by small-scales individual farmers on fragmented lands following the informal seed system, where the producers used seed of inferior quality. The absence of organizations that are involved in multiplication of improved quality and certified potato seed tuber is a serious problem. Seed tuber multiplication activities are mainly handled by individual farmers, cooperatives, which often lack even basic amenities for proper multiplication of seed tuber in sizable quantity, and high quality. Moreover, the few private seed producers company operating in the country that produce potato seed follow traditional methods and lack adequate infrastructure. Therefore, most of the challenges for potato research and developments are as follows;

- Limited knowledge on seed and ware potato production techniques
- Limited improved varieties and germplasm for diverse agro-ecologies
- Shortage of quality and healthy seed tuber/planting materials
- Diseases and insect pests (late blight, bacterial wilt, viruses and PTM)
- Postharvest, processing, utilization, handling and management (packaging, storage processing techniques, value addition)
- Lack of storage facilities for ware and seed potato tubers and limited agro-processing industry and variety for processing
- Poor agronomic (spacing, fertility, ridging) and irrigation practices
- Poor transportation and marketing systems
- Limited capacity (human power, facility and infrastructure)
- Limited financial support for research and developmen
- Lack of formal seed system (dominated by informal seed system)

11. Future research and development direction

- Supply of agricultural technologies such as new varieties, proper production practices
- Capacity building activities (training, infrastructure)
- Development of varieties adaptable to different agro-ecological zone, resistance to late blight, early maturing with good quality for taste & market.
- Development of varieties suitable for processing.
- Developing techniques for healthy and quality seed tuber production.
- Client oriented research that involves different stakeholders.
- Disease & insect pest management (IDM, IPM)
- Strengthening of informal seed tuber production in farmers field and promote for the establishment of formal seed system.
- Post harvest technology development (seed and ware storage, utilization).
- Encourage private investors to involve in seed production and processing potatoes.
- Create strong linkages between different stakeholders
- Scaling up/out of technologies (popularize the technologies for beneficiary)

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